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Soft limiter for oscillator circuits uses emitter-degenerated differential pair

Herminio Martínez and Encarna Garcia,
Technical University of Catalonia, Barcelona, Spain

Most oscillator circuits include a nonlinear amplitude control that sustains oscillations at a desired amplitude with minimum output distortion. One approach uses the output sinusoid's amplitude to control a circuit element's resistance, such as that of a JFET operating in its triode-characteristics region. Another control method uses a limiter circuit that allows oscillations to grow until their amplitude reaches the limiter's threshold level. When the limiter operates, the output's amplitude remains constant. To minimize nonlinear distortion and output clipping, the limiter should exhibit a "soft" characteristic.

Based on a waveform shaper that imposes a soft limitation or saturation characteristic, the circuit in **Figure 1** comprises a simple RC (resistor-capacitor)-ladder phase-shift oscillator and an amplitude-control limiter circuit. R_1, R_2, and R_3 have values of 10 kΩ each, and C_1, C_2, and C_3 have values of 1 nF each. The following **equation** defines output voltage V_{OUT}'s frequency, f_O.

$$f_O = \frac{\sqrt{6}}{2\pi RC} = \frac{\sqrt{6}}{2\times\pi\times 10\ k\Omega\times 1\ nF} \approx 39\ kHz.$$

The inverting-amplifier block in **Figure 1** comprises transistors Q_1 and Q_2, a differential pair that presents a nonlinear-transfer characteristic, plus an IVC (current-to-voltage converter) based on operational amplifier IC_1. For oscillation to occur, the inverting amplifier's gain magnitude must exceed 29. Selection of appropriate values of bias current, I_{EE}; the transistor pair's emitter-degeneration resistances, R_{E1} and R_{E2}; and R_{E3} produces the amplifier's nonlinear-transfer characteristic, V_{OUT} versus V_{IN} (**Figure 2**).

A small input voltage produces a nearly linear-amplifier-transfer characteristic. However, large values of input voltage drive Q_1 and Q_2 into their nonlinear region, reducing the amplifier's gain and introducing a gradual bend in the transfer characteristic. A current mirror comprising Q_3 and Q_4 converts the shaping circuit's output

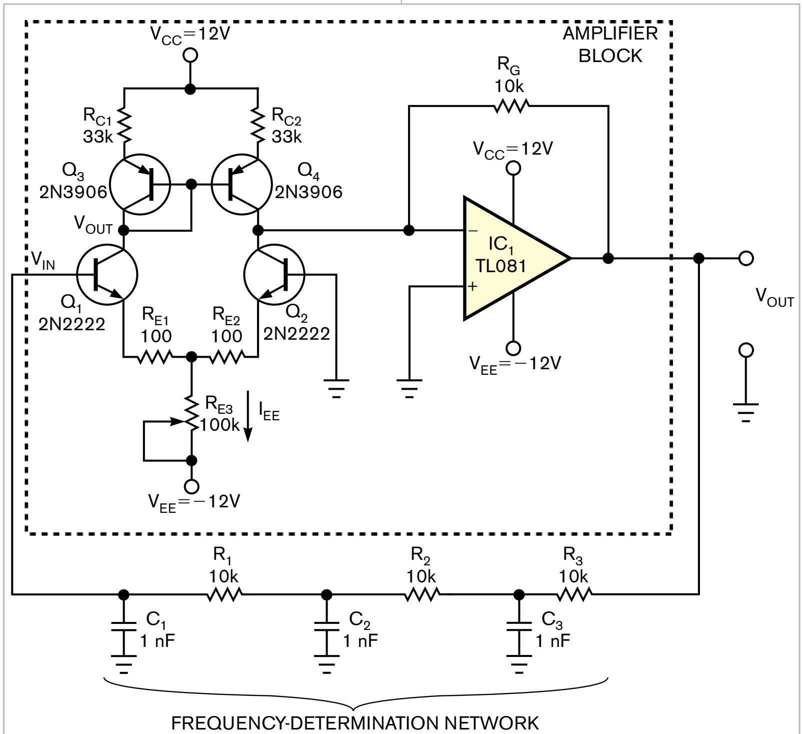

Figure 1 A phase-shift RC-oscillator circuit uses an emitter-coupled amplitude limiter.

to a single-ended current, which operational amplifier IC_1 converts to an output voltage. In the prototype circuit, calibration trimmer R_{E3} has a value of approximately 33 kΩ. **Figure 3** shows the oscillator's output voltage for the component values in **Figure 1**, and **Figure 4** shows the sinusoidal output's spectral purity.

The nonlinear amplifier's wave-shaping action occurs independently of frequency, and this circuit offers convenience for use with variable-frequency oscillators. Note that IC_1's gain-bandwidth product limits the circuit's performance. To use the limiter portion of the circuit with a noninverting amplifier, such as a Wien-bridge oscillator, apply the signal input voltage to Q_2's base, and ground Q_1's base. EDN

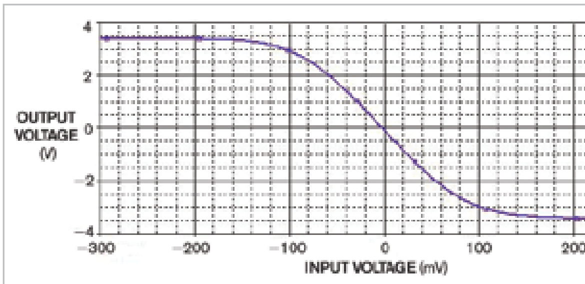

Figure 2 The transfer-characteristic output voltage versus input voltage for the nonlinear amplifier shows a gradual onset of limiting at approximately 100-mV input.

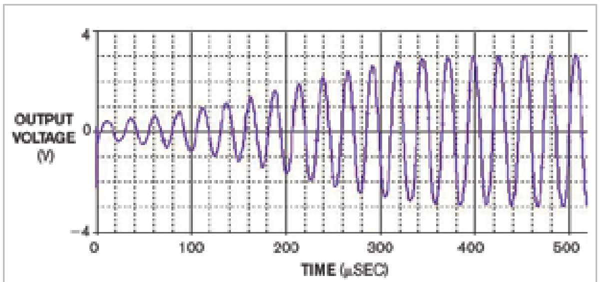

Figure 3 For the component values in Figure 1, the oscillator's output voltage reaches full amplitude in approximately 400 μsec, or 15 cycles after start-up.

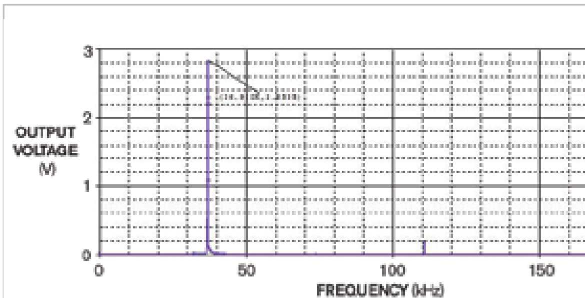

Figure 4 The oscillator's output spectrum shows only a slight amount of third-harmonic output.

Feedback circuit enhances phototransistor's linear operation

JC Ferrer and A Garrigós, University Miguel Hernández, Elche, Spain

A designer who uses a phototransistor to convert a modulated optical signal to an electrical signal frequently encounters problems when high-intensity background light saturates the phototransistor. When its base terminal floats, a phototransistor's collector-to-emitter voltage depends only on the photocurrent generated by the superposition of the signal and background light. The phototransistor's gain and its active-region range depend on R_1's resistance. For higher values of R_1, the circuit's gain increases, but the phototransistor saturates more quickly. In **Figure 1**, without background illumination, the transistor operates in its linear region at bias point ϕ_2, and Q_1's collector voltage varies linearly

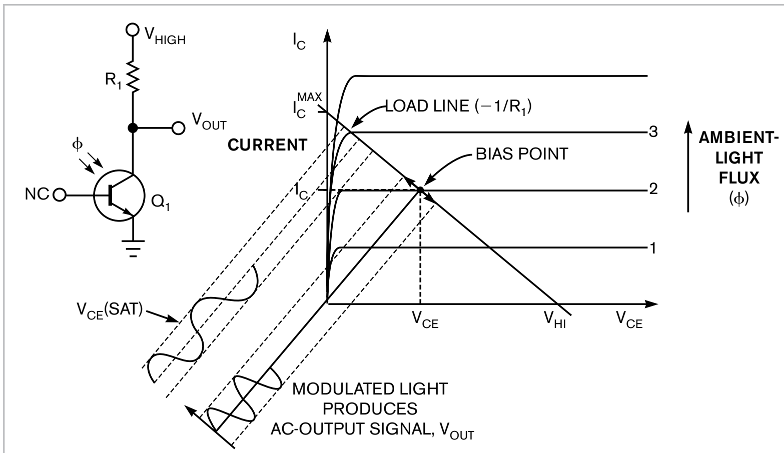

Figure 1 Varying levels of ambient-light flux affect the bias point of a basic phototransistor circuit. Higher levels force the bias point closer to saturation and compress the desired signal, V_{OUT}.

around V_{CE}. Its output, V_{OUT}, faithfully reproduces ampltude fluctuations in the modulated optical signal. Applying extraneous steady-state background illumination shifts the circuit's operating point to bias point ϕ_3, and the output voltage compresses and distorts.

Unlike photodiodes and photovoltaic cells that have only two leads, a phototransistor's base connection allows a feedback circuit to control the device's bias point. Diverting current from the base terminal reduces collector current. In **Figure 2**, phototransistor Q_1 detects an optical signal plus background light that illuminates its base region. A lowpass active filter samples the collector voltage generated by the background light, and a Howland current source alters the circuit's bias point by draining current from the phototransistor's reverse-biased collector-base junction.

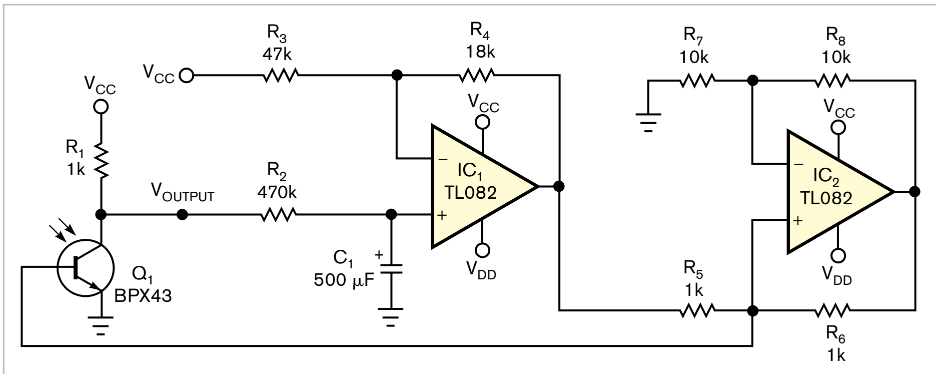

Figure 2 A feedback circuit consisting of a single-pole lowpass active filter and a Howland source diverts current from the phototransistor's base to avoid saturation at excessive background-light levels.

In general, extraneous background illumination fluctuates more slowly than the desired signal. For simplicity, this design uses a first-order lowpass filter, C_1 and R_2, with a cutoff frequency below the signal frequency to sample Q_1's collector voltage. Applying a reference voltage—V_{CC}, in this example—to R_3 sets the filter circuit's dc operating point midway between the phototransistor's cutoff and saturation voltages. The lowpass filter's output drives a Howland current source to produce a current proportional to the filter's output. As background illumination increases, Q_1's collector voltage decreases. The current source's output subtracts from Q_1's base current, which in turn raises Q_1's collector voltage to avoid saturation.

The ratio of R_4 to R_3 establishes the active lowpass filter's gain according to the equation $A_V=1+(R_4/R_3)$, and R_5 sets the current source's transconductance: $G_M=1/R_5$. Altering these resistors affects the amount of current drained from the phototransistor's base and the circuit's operating point. The phototransistor has much lower capacitance than the filter, ensuring that the circuit in **Figure 2** cannot oscillate. However, replacing the first-order lowpass filter with a second-order lowpass filter requires careful selection of the capacitors' values to avoid oscillation.

Illuminating the phototransistor with a 100W incandescent light bulb provides high-intensity-light background lighting plus a rapidly changing signal due to the applied ac-line

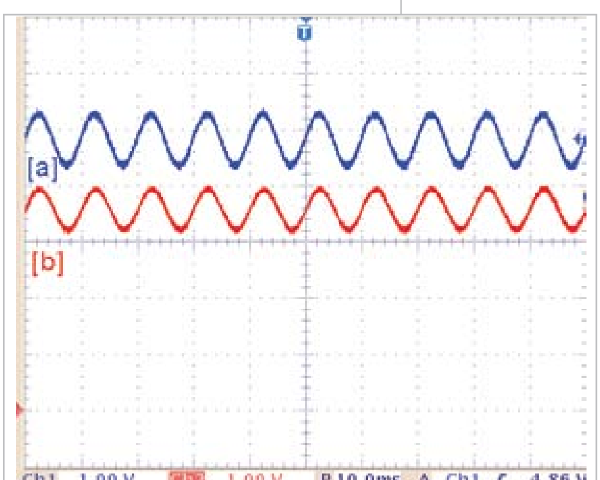

Figure 3 A 100W light bulb at a 40-cm distance illuminates a collector-emitter voltage of a phototransistor with a feedback circuit (a) and with no feedback (b). Both bias points remain in the linear region.

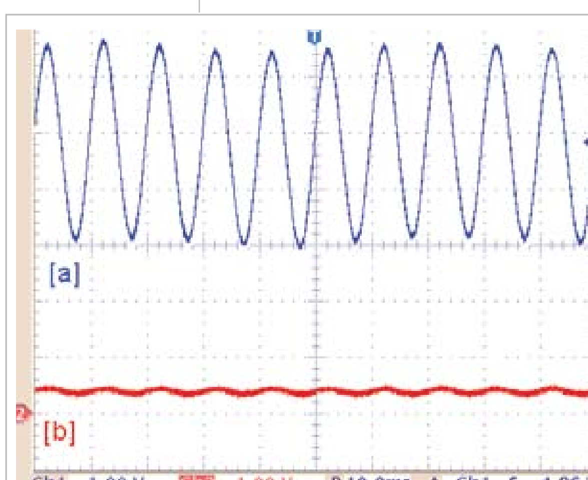

Figure 4 A 100W light bulb at a 20-cm distance illuminates the collector-emitter voltage of a phototransistor with a feedback circuit (a) and with no feedback (b). Saturation of the circuit with no feedback prevents signal detection.

voltage. **Figure 3** shows Q_1's collector-to-emitter voltage with the light bulb 40 cm from the phototransistor with the feedback circuit active (**Figure 3a**) and for the circuit with the phototransistor's base floating (**Figure 3b**). The responses appear similar because the phototransistor doesn't saturate at the applied light intensity.

Repositioning the light bulb at 20 cm from the phototransistor increases the background-light level and drives the phototransistor closer to saturation. When you apply feedback, the phototransistor delivers a higher amplitude signal, although its bias point remains almost unchanged (**Figure 4a**). The average dc-voltage level at Q_1's collector remains almost the same as at the lower light level (**Figure 3a**). However, with no feedback applied, the phototransistor's bias point moves close to saturation, and the ac-modulated light variations are barely detectable (**Figure 4b**).EDN

Three-phase sinusoidal-waveform generator uses PLD

Eduardo Perez-Lobato, University of Antofagasta, Antofagasta, Chile

Using the circuit in this Design Idea, you can develop and implement a lightweight, noiseless, inexpensive, three-phase, 60-Hz sinusoidal-waveform voltage generator. Although targeting use as a circuit for testing power controllers, it can serve other applications that require three sine waves with a 120° relative phase difference. A 22V10 PLD (programmable-logic device) at IC_1 generates three three-phase, 60-Hz, square-wave voltages. Internal register IC_1 and Q_0, Q_1, and Q_2 bits set the

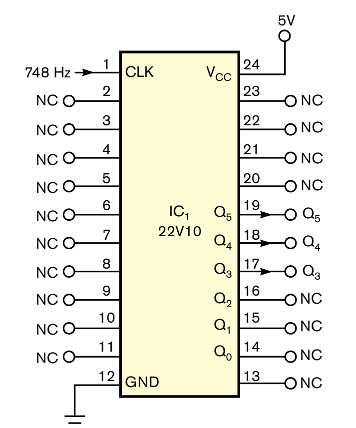

Figure 1 An external 748-Hz clock source drives this PLD-based, three-phase sine-wave generator.

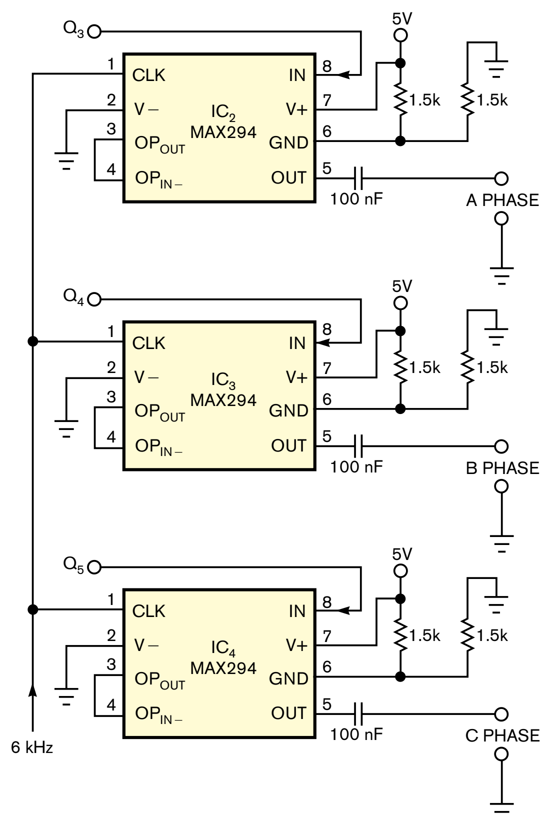

Figure 2 Switched-capacitor filters remove all but the sinusoidal fundamental signal from the PLD's three-phase square-wave outputs.

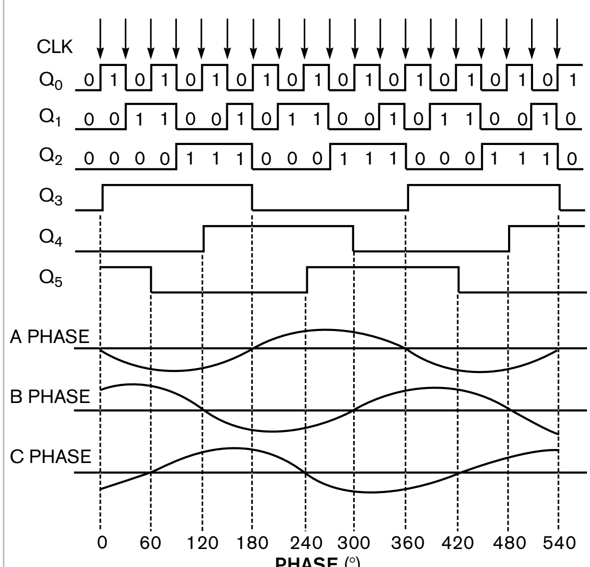

Figure 3 The timing diagram shows the relationship between the clock and the three-phase outputs.

Q_3 bit to lead the Q_4 bit by 120° and set the Q_5 bit to lag behind the Q_3 bit by 240° (**Figure 1**). Setting IC_1's clock frequency to 748 Hz produces 60-Hz outputs at Q_3, Q_4, and Q_5.

IC_1's three square-wave output voltages—Q_3, Q_4, and Q_5—drive IC_2, IC_3, and IC_4, three Maxim (www.maxim-ic.com) MAX294 eighth-order, lowpass, switched-capacitor filters to produce three 2V sinusoidal waveforms (**Figure 2**). When you connect IC_5, a common 555 timer as an astable oscillator, it produces a 6-kHz, TTL-level source that clocks all three filters at 100 times the desired 60-Hz output frequency. A 100-nF dc-blocking capacitor at each filter's output ensures that the three-phase outputs swing from +2 to −2V with respect to ground. Note that each filter inverts its output and introduces a 180° phase shift with respect to its input square wave.

Figure 3 depicts the phase relationships among IC_1's outputs and yields Boolean equations (**Table 1**). The equations translate into set/reset signals that produce 64 logic states when you apply them to a 6-bit sequencer block in IC_1. Outputs Q_5, Q_4, and Q_3 represent the three most-significant bits, and Q_2, Q_1, and Q_0 represent the three least-significant bits. After translation, an emulated Basic program (**Listing 1**), which you can download from www.edn.com/061012di1, produces fuse-programming code for IC_1's sequencer and logic states. Although only 16 logic states define the sequencer's functions, its remaining 48 states also require definition to avoid anomalous operation. EDN

TABLE 1 BOOLEAN EQUATIONS

$SET\_Q_0=\overline{Q_0}$	$RESET\_Q_0=Q_0$
$SET\_Q_1=\overline{Q_1}\times Q_0$	$RESET\_Q_1=\overline{Q_2}\times Q_1\times\overline{Q_0}+Q_2\times Q_1\times\overline{Q_0}$
$SET\_Q_2=\overline{Q_2}\times Q_1\times\overline{Q_0}$	$RESET\_Q_2=Q_2\times Q_1\times\overline{Q_0}$
$SET\_Q_3=\overline{Q_3}\times Q_2\times Q_1\times\overline{Q_0}$	$RESET\_Q_3=Q_3\times Q_2\times Q_1\times\overline{Q_0}$
$SET\_Q_4=\overline{Q_4}\times Q_2\times\overline{Q_1}\times\overline{Q_0}$	$RESET\_Q_4=Q_4\times Q_2\times\overline{Q_1}\times\overline{Q_0}$
$SET\_Q_5=\overline{Q_5}\times\overline{Q_2}\times Q_1\times\overline{Q_0}$	$RESET\_Q_5=Q_5\times\overline{Q_2}\times Q_1\times\overline{Q_0}$

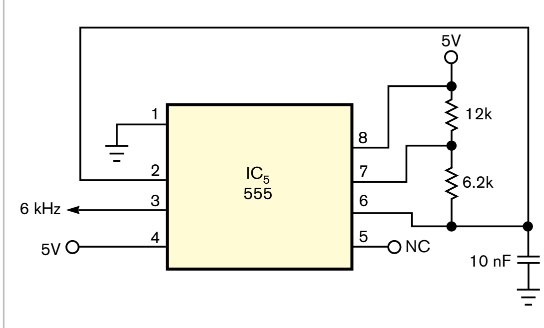

Figure 4 A garden-variety 555 timer IC provides a 6-kHz clock for the switched-capacitor filters.